Don't "Waste" Your Energy

Educational Module
NREL 2001

Author:
Gregory A. Manier

Grade Level/Subject:
8^{th}-12^{th} grade science. Application to math course as extension of quantitative analysis.

National Science Education Standards Applications:
- Content Standard A- Possess abilities necessary to do scientific inquiry.
- Content Standard B- Develop an understanding of structure and properties of matter, chemical reactions, and interactions of energy and matter.
- Content Standard D- Acquire understanding of energy in the earth system, and geochemical cycles.
- Content Standard F- Develop understanding of personal and community health, population growth, natural resources, environmental quality, human induced hazards and science and technology in local, national, and global challenges.

Purpose:
Bring Biomass energy potential to the classroom using analysis of waste produced in ordinary American households.

Objectives:
After completing this lesson students will be able to:

- Calculate and realize the amount of waste produced by individuals in the class on a daily, weekly, monthly and yearly basis.
- Work in a group format to compile data.
- Determine the origin and characteristics of waste products and identify possibilities for use as energy sources.
- Apply the carbon cycle to our fossil fuel consumption and understand the importance of a reduction in their use.
- Assemble laboratory equipment to perform an experiment.
- Demonstrate the potential of organic waste products to produce fuels.

Materials Needed:
Collection containers (plastic trash bags)
Scale
Large test tubes
One hole rubber stoppers
Stand with clamp to hold test tube
Matches
Gas Burner
Data Tables
Safety Goggles

Preparation:
Day 1:
- Knowledge of Biomass energies and their advantages is helpful before presenting this lesson. See background knowledge section for references to literature on the topic.
- Gather up to date data on waste production in the US and the world. Data has been provided up to 1998, but more accurate numbers are helpful to add accuracy as well as validity.

Day 2:
- Set up stations for weighing items
- Provide data tables.
- Provide gasification materials. See diagram 1.

Time Requirements:
2 hours total, 30 minutes day 1, 75-90 minutes day 2.

Background Knowledge/Introduction:
References: **http://www.epa.gov/epaoswer/non-hw/muncpl/msw99.htm** - the above website is provided by the Environmental Protection Agency, entitled Characterization of Municipal Waste in the United States. It will provide the most accurate data possible. (see waste stream generation chart)
http://members.tripod.de/cturare/pro.htm – gasification information.

Day 1: (25-30 minutes)

Part 1: Recognizing Resources

• Create a chart on the board or overhead and list natural resources categorized as either renewable or non-renewable and the destination or final product produced with each (ex. Natural gas, non-renewable, product is heat for homes). This should go very quickly. Encourage discussion after lists have been generated as to how we are using each resource, where it is found globally, and problems associated with their usage.

Part 2: Your Garbage is OUR Garbage

• Either pass out trash bags, or have them bring their own. Explain that you are going to be looking at a resource that was most likely not listed, garbage.

- The assignment is to collect **every** item of garbage that they produce in a 24 hour period. This will require some discussion as to what should be collected. Emphasize that they must be very mindful to not throw out items. Also, explain that there are items not appropriate to collect, such as products that may contain bodily fluids, any hazardous material, or items that they did not directly generate. (ex. bag from dog's food)

- A main problem that can be encountered is shared waste products. (ex. box of spaghetti that whole family eats for dinner) Use discretion to get the most accurate numbers possible. A suggestion would be to cut items like this into pieces proportional to number of members in the family. It could also become a good discussion point on Day 2.

- To close the class, have students estimate their garbage production weight for a 24-hour period. Record these # for future reference.

Day 2: (60-75 minutes)

Part 1: The World's Garbage Problem

- Pass out data table #1

- Determine weight of each students waste production, and allow them to work on the data table for 5-10 minutes. Bring out yesterday's data and let students compare and record their predicted numbers with their actual data.

- As numbers begin to come in, begin a discussion of the amounts of waste produced in the nation each year. (see EPA data table) Where does it all go? Where else?

Part 2: What's Really In Garbage?

- Group students into teams of four to complete the rest of the lesson.

- Pass out data table #2. Make sure students know how to define organic and inorganic.

- Each student is allowed to pick one (their favorite) piece of garbage from their bag to be analyzed. Record the teams four items by name on their data tables. Use a few items as examples of how to fill out the table. Chose items from different origins to encourage data diversity. Make sure they are getting to (or attempting) the true origin of the materials. (ex. not just paper, trees are the real source). This should be a brainstorming process. Allow mistakes to be made concerning origin. (ex. where does glass come from?) Decomposition time should be a rough estimate. Use fast, medium and slow as general categories for this column. Let them work as a group to fill out their tables.

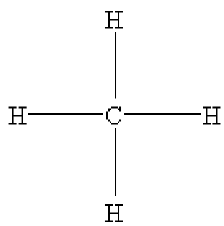
- Have each group present one or two of their items, with data recorded, to the class.

Part 3: Gasification Modeling!

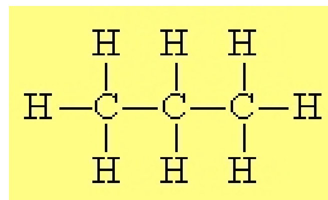
- Revisit the concept of substances that are classified as **organic.** Discuss the significance of all organic matter being constructed of the same elements (N, O, C, H).

- Fuels that are familiar to all students are methane and propane. Their simple structures allow them to be easily drawn on the board. (see following)

METHANE



PROPANE



- With the catalyst of heat, these elements found in organic material, will form fuels like methane and propane. A good example is wood burned for fuel. The carbon and hydrogen already present in the wood are chemically reacted (using heat) to form these fuels.

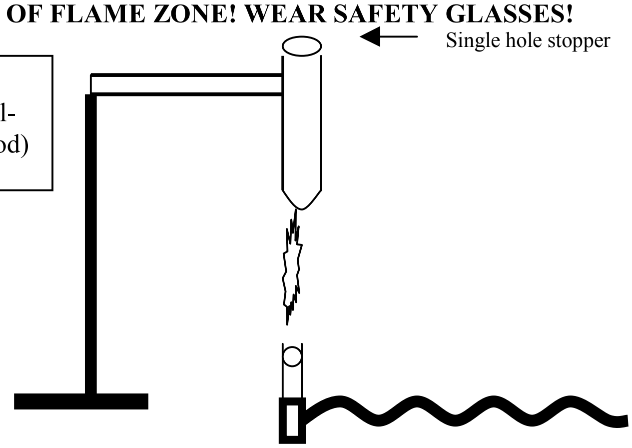
- **We can collect these fuels without directly burning the substance. This process is called gasification.** Heating organics in a test tube will produce some of these gases. If we can collect these gases in a concentrated stream, we can demonstrate their flammability and thus their energy potential. The single holed stopper will serve as the port for the stream of gases produced in the reaction.

•. Have each group pick one item from their waste that they feel is certainly made of organics. They should cut the material into the smallest pieces possible, and have enough to fill the test tube about 1.5-2.0 inches.

- Large test tubes should be securely mounted on ring stand. Burners placed underneath in close proximity.

- Apply direct heat to the bottom of the test tube. As the material begins to "gasify" the fuels will be ejected out the top of the stopper. Ignite the area just above the hole. **These fuels drive the process to produce electricity in a power plant designed for the material! SAFETY IS A MAJOR CONCERN WITH FLAME. KEEP BODY PARTS OUT OF FLAME ZONE! WEAR SAFETY GLASSES!**

Diagram 1. Apparatus should be installed in well-ventilated area. (fume hood)



Grading Rubric- Don't "Waste" Your Energy.

Criteria	Below Standards	Meets Standards	Exceeds Standards
Participation	Minimal discussion of resources and garbage origins.	Engages in discussion.	Engages in discussion, shares new ideas, brings issues to group work.
Collection	Brings less than full amount of 24 hour period collection.	Brings accurate collection.	Brings accurate collection with discussion of accuracy concerning family data.
Math	Does not complete data table #1	Completes data table #1	Completes data table #1. Provides assistance to group work. Checks for accuracy.
Experiment	Does not assist. Apparatus is not assembled correctly. Does not function. Safety concerns.	Apparatus assemble correctly. Gasification demonstrated. Follows safety procedures.	Assists others with assembly. Gasification demonstrated. Follows safety procedures.
Critical Thinking	Does not analyze content critically for uses in real world.	Finds real world application to process. Can discuss garbage energy potential.	Can discuss garbage problem for environment. Sees energy potential. Understands molecular production of fuels.

Parts of the following are in a publication** By ***Janet Cushman**, *Gregg Marland*, *and Bernhard Schlamadinger from Oak Ridge National Laboratory, Tennessee. DOE.***

*****The report does a very good job looking critically at Biomass as a potential energy source, and should be read by students who are capable of thinking critically and discussing topics objectively. It can be used as a pre-lab homework assignment, or as an in class reading for background knowledge.***

GASSIFICATION IS NOT A DIRTY WORD

SOME BIG REASONS WHY AND HOW IT CAN HELP

There is widespread concern that observed increases in the concentration of carbon dioxide and other greenhouse gases in the earth's atmosphere will ultimately lead to changes in the earth's climate. Although it is clear that the atmospheric concentration of carbon dioxide is increasing and that the increase is being driven in large measure by the **burning of fossil fuels** (coal, oil, and natural gas), the climatic consequences of increasing atmospheric carbon dioxide are not so clear. Recognizing that fossil fuels play a very important role in the economies and lifestyles of people throughout the world, and acknowledging that great uncertainty exists regarding the climatic consequences of burning fossil fuels, it is reasonable to ask if the global economy can be powered in ways that might have **less impact on the environment** because they discharge less carbon dioxide.

Carbon Storage vs Energy Use

The potential role of **biomass energy** acquired a new dimension when it was suggested that planting large areas of new forest could slow the increase in atmospheric carbon dioxide by removing carbon dioxide from the atmosphere. Two questions then arose: How does using trees to remove carbon dioxide from the atmosphere compare with using biomass as a fuel, and how do these possibilities compare with harvesting forests for conventional wood products?

Fast-growing trees can recycle carbon rapidly and will displace fossil-fuel use.

There are two common, but mutually exclusive, impressions about biomass fuels and carbon dioxide. One first impression is that biomass fuels and fossil fuels are not different because, when burned, both yield carbon dioxide. This is true if land from which biomass is harvested for fuel is not replanted and instead is converted to other uses. However, if the biomass is produced sustainably, the growing trees and other plants remove carbon dioxide from the atmosphere during photosynthesis and store the carbon in plant structures. When the biomass is burned, the carbon released back to the atmosphere will be recycled into the next generation of growing plants. When biomass is used for fuel in place of fossil fuels, the carbon in the displaced fossil fuel remains in the ground rather than being discharged to the atmosphere as carbon dioxide. The productivity, or rate of growth of the trees, becomes an important consideration. While slow-growing trees can take a very long time before the released carbon is recaptured in the next generation of trees, fast-growing trees can recycle carbon rapidly and will displace fossil-fuel use with every cycle.

Wood chips from fast-growing trees are stored in Hawaii.
These chips will later be used as fuel.

A second impression is that **biomass energy systems**, because they **recycle carbon**, produce no net emissions of carbon dioxide. This is **not strictly true** either. It takes some energy, much of it now provided by fossil fuels, to grow and harvest biomass fuel crops and to haul the fuel to a power plant. The use of biomass fuels does result in some discharge of carbon dioxide. The extent to which biomass fuels can displace net emissions of carbon dioxide will **depend on the efficiency** with which they can be produced and used.

Forests that are not harvested do not continue to accumulate carbon indefinitely. They eventually approach maturity and achieve, over time, **a balance between the carbon taken up in photosynthesis and the carbon released back to the atmosphere from respiration, oxidation of dead organic matter, and fires and pests.** If fossil fuels continue to be used to meet society's energy needs, reforestation or afforestation of ever larger areas would be needed to prevent increasing concentrations of atmospheric carbon dioxide. Does it make more sense to use trees for energy and to recycle carbon than to store carbon in forests while continuing to burn fossil fuels? Although the system is complex and critical variables are different in different places, it is important to understand the choices available.

Land Use and Carbon Dioxide

Scientists at ORNL have begun to examine a variety of land management alternatives, including whether substituting biomass fuels for fossil fuels could be an effective strategy for reducing net emissions of carbon dioxide to the atmosphere. How can limited resources of land be used most effectively to minimize net emissions of carbon dioxide to the atmosphere while meeting the energy requirements of our global society? Should we preserve existing forests, plant new forests, or develop biomass-based energy systems, or should we encourage the use of long-lived wood products? Is there some other or mixed strategy that is most attractive for minimizing the net emissions of carbon dioxide?

ORNL scientists examine whether substituting biomass fuels for fossil fuels could cut emissions of CO2.

In this discussion we focus on minimizing the risk of global climate change through minimizing carbon dioxide emissions, but we recognize that other criteria go into land-use decisions. Many of these are being evaluated in other portions of ORNL's assessment of biomass energy resources and opportunities. For example, in some regions of the world, deforestation is a major source of carbon dioxide emissions. Currently, an estimated 15 to 20% of atmospheric carbon dioxide emitted by human activities results from deforestation or, more generally, from changes in land use. Clearly, many motivations, including the need for food production, are involved in decisions on land use and will affect the amount of land available for reforestation or for biomass energy crops. Although we are considering the possibility of planting new areas of forest, the rate of growth in atmospheric carbon dioxide could also be reduced substantially by decreasing the current rate at which forest is being converted to other land uses. Coincidentally, **the amount of carbon dioxide emitted annually from deforestation around the world is of the same order of magnitude as the amount of additional carbon dioxide that would be discharged if the 14% of primary energy now supplied by biomass fuels globally were instead supplied by oil and coal.**

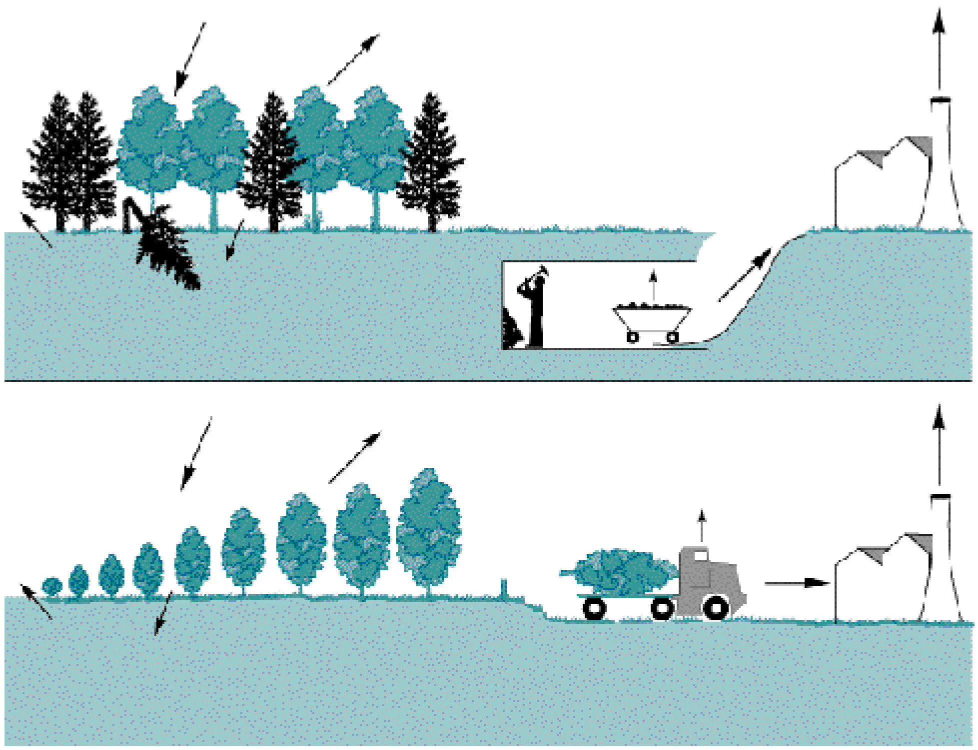
The net impact of land management and the use of biomass-based products on the cycling of carbon will depend on the type of land used, the management practices used on that land, how the biomass products are used, and the time frame of the analysis. Especially important are how much carbon is stored on the land (including in trees and other plants and in the soil and plant litter on the ground) at the beginning and end of the analysis, how much fossil-fuel use is displaced, how much carbon is stored in durable wood products, and how much energy is required for forest and other land-management operations. Also important are how efficiently forest and other biomass products are used and the alternate products for which they substitute, including whether biomass fuels are substituted for coal, oil, or natural gas; whether they are used to produce liquid fuels, heat, electric power, or some combination of these; and the efficiency with which they are used. The net impact on carbon cycling will depend on the mix of forest and other biomass products used for short-lived products like paper, long-lived products like construction lumber, and fuels. It will depend on whether the lumber displaces aluminum, concrete, glass, or plastic. It will depend ultimately on whether the waste products are reused, buried in landfills, burned for energy, or incinerated.

If production of biomass energy is the goal, a fast-growing herbaceous crop such as switch grass may be the best choice.

Although we have focused on trees and forest products in our analyses to date, the most advantageous land use for confronting the carbon balance may not necessarily involve trees. If the primary intent is to store carbon on site, the obvious choice is a high-density forest. On the other hand, if production of biomass energy is the goal, a fast-growing herbaceous crop such as switch grass may be the best choice for some biomass energy technologies and some types of land. Under other circumstances, wood, biodiesel, or another fuel may be able to displace the most fossil fuel. And, if we broaden consideration to include other biomass products, we may find other alternatives. It is important to examine the full range of the affected system and to see how the carbon balance is affected.

Modeling Carbon Flows

To illustrate the impacts of some land-management alternatives on net carbon emissions, we use a simple mathematical model to compare two scenarios. In the first scenario (top half of the figure) 1 hectare of land is used to grow trees to store carbon for 50 years. During this period, a coal-fired power plant is used to generate electricity. In the second scenario (bottom half of the figure), the trees are harvested each time they reach an appropriate size and are used to displace some of the coal that would otherwise be burned. At the end of 50 years, there will be more carbon stored in living trees in the first scenario, but there will also have been more coal burned than in the second scenario. The net difference in carbon dioxide added to the atmosphere depends on how fast the trees grow and how efficiently they are harvested and converted into useful energy. The net carbon balance also depends on the amount of biomass on the land at the beginning of the analysis. If, for example, the land were already occupied by mature forest, carbon would continue to be stored but little or no additional carbon would be accumulated. On the other hand, unforested land could have a very large capacity to accumulate additional carbon in trees. Both the rate of accumulation of carbon in the forest (scenario 1) and the amount of coal displaced (scenario 2) depend on the growth rate of the trees.



***Top*: Growing forest accumulates carbon until it achieves, over time, a balance between the carbon taken up in photosynthesis and the carbon released back to the atmosphere from respiration, oxidation of dead organic matter, and fires and pests. In the meantime, fossil fuels are used to meet society's energy needs. *Bottom*: In productive forests, trees can be harvested for use in producing heat or power. Although harvesting may result in less carbon stored in standing biomass and forest soils, biomass fuels replace some of the fossil fuel that would otherwise be burned. The carbon in that fossil fuel remains stored in the ground rather than being released to the atmosphere. In both scenarios there are some energy needs for gathering the resource and converting it into useful energy, but, as the arrows on the transportation system suggest here, these are generally comparatively small. Arrows provide a qualitative indication of the magnitude and direction of carbon flows.**

By comparing the results of these and other scenarios under a variety of initial conditions, biomass growth rates, and end uses, we begin to get some clues to the most carbon-efficient ways to manage forest or other lands and to the potential for biomass fuels to mitigate the increase in atmospheric carbon dioxide. The comparisons show that when the amount of forest biomass on the land in the beginning is very large and the productivity of the land is low, the most effective strategy is to allow the trees to grow, to stand, and to store carbon. In other words, slow-growing old-growth forests are best left in place. Similarly, the net carbon balance on degraded lands with low productivity is best when they are reforested, without harvesting, to store carbon.

The rate of accumulation of carbon in the forest and the amount of coal displaced depend on the growth rate of the trees.

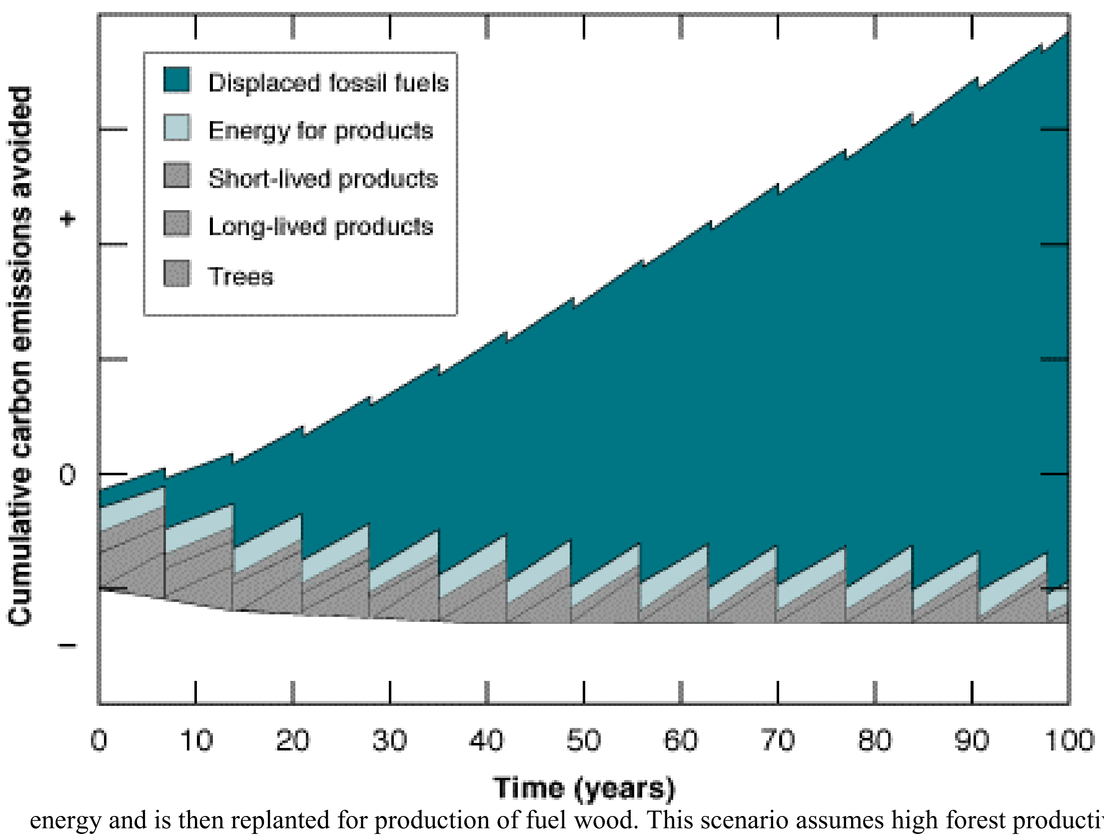
Results are quite different on lands that can support high growth rates. There, the net reduction in carbon dioxide emissions is far greater if the trees are harvested and used as a fuel, with prompt replanting, than if the trees are left unharvested for carbon storage. On such lands, several generations of fast-growing trees (such as poplars) can be harvested in 50 years, displacing additional fossil fuel with each harvest. There are also intermediate productivities where the choices are not so clear-cut and the sign of the net carbon balance depends on other variables such as the efficiency with which biomass is substituted for fossil fuels.

Fast-growing trees can be harvested in 50 years, displacing additional fossil fuel with each harvest.

Using current technologies, the most efficient way to convert biomass to useful energy, and thus to maximize the carbon dioxide savings, is to burn the biomass for heat or electricity generation, displacing coal. In all scenarios, carbon dioxide benefits increase as biomass growth rates increase and as utilization efficiency increases. The Biofuels Feedstock Development Program at ORNL aims to increase the productivity of tree and grass crops and improve the efficiency of biomass feedstock supply systems. Improvements in these areas offer a large payback both in the economics of biomass fuels and in the potential for net reductions in carbon dioxide emissions.

A more comprehensive model of carbon flows is now being developed at Joanneum Research in Graz, Austria, in collaboration with ORNL. This spreadsheet model allows us to calculate the carbon balance of land management and biomass utilization strategies. It can consider different types of biomass fuels as well as other biomass-based products from forestry or agriculture. Input parameters for the model describe the growth rate, rotation length, management intensity, previous land use, carbon dynamics of the soil and litter, fate and life expectancy of the harvested products, efficiency of fossil-fuel substitution, and energy required for land management. Model output is shown in diagrams with time on the horizontal axis and cumulative net reduction in carbon emissions on the vertical axis.

To illustrate the variety of factors that come into consideration, the following figure shows model results for a scenario in which a forest is harvested for a conventional mix of long- and short-lived products and

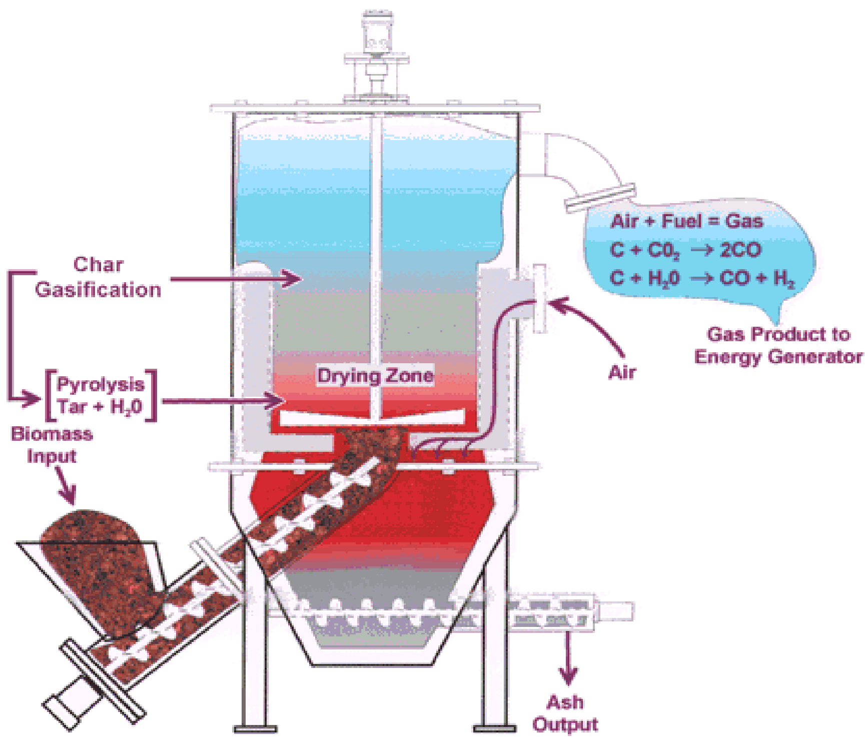


energy and is then replanted for production of fuel wood. This scenario assumes high forest productivity and high efficiency in use of the fuel wood. Note that the carbon in wood products is gradually released to the atmosphere over time as the products decay. Some carbon is lost from soils (reflected in the drop in the bottom line of the figure) as the forest is converted to shorter rotations with more frequent harvests. Most strikingly, the net savings of carbon emissions continues to build over time as coal consumption is displaced.

Much remains to be learned about the potential for producing and using biomass fuels to reduce carbon emissions. However, **initial studies of the carbon balance suggest that biomass fuels could play a significant role in minimizing net emissions of carbon dioxide to the atmosphere**. And, very importantly, the initial studies suggest that the optimal strategy will be different from place to place, determined by the quality of the land, its current uses, competing uses, and the demands for energy and other products. Continuing studies at ORNL and at Joanneum Research will explore the potential of biomass fuels as a strategy for confronting global climate change.

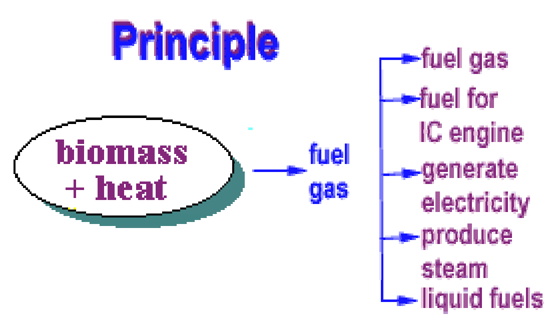
The Inner Workings of a Simple Gasifier

Principles of Gasification



Advantages

- can use waste products to produce useful energy
- help eliminate landfill problems
- CO_2 neutral process
- choice of energy form produced



MATERIALS GENERATED* IN THE MUNICIPAL WASTE STREAM, 1960 TO 1998 (In thousands of tons and percent of total generation)								
Materials	**1960**	**1970**	**1980**	**1990**	**1995**	**1996**	**1997**	**1998**
Paper and Paperboard	29,990	44,310	55,160	72,730	81,670	79,680	83,290	84,130
Glass	6,720	12,740	15,130	13,100	12,830	12,290	12,010	12,450
Metals								
Ferrous	10,300	12,360	12,620	12,640	11,640	11,830	12,330	12,380
Aluminum	340	800	1,730	2,810	2,960	2,950	3,010	3,080
Other Nonferrous	180	670	1,160	1,100	1,260	1,260	1,270	1,380
Total Metals	10,820	13,830	15,510	16,550	15,860	16,040	16,610	16,840
Plastics	390	2,900	6,830	17,130	18,900	19,760	21,470	22,370
Rubber and Leather	1,840	2,970	4,200	5,790	6,030	6,200	6,590	6,860
Textiles	1,760	2,040	2,530	5,810	7,400	7,720	8,240	8,600
Wood	3,030	3,720	7,010	12,210	10,440	10,840	11,570	11,930
Other **	70	770	2,520	3,190	3,650	3,690	3,760	3,900
Total Materials in Products	54,620	83,280	108,890	146,510	156,780	156,220	163,540	167,080
Other Wastes								
Food Wastes	12,200	12,800	13,000	20,800	21,740	21,850	21,910	22,130
Yard Trimmings	20,000	23,200	27,500	35,000	29,690	27,920	27,730	27,730
Miscellaneous Inorganic Wastes	1,300	1,780	2,250	2,900	3,150	3,200	3,250	3,290
Total Other Wastes	33,500	37,780	42,750	58,700	54,580	52,970	52,890	53,150
Total MSW Generated - Weight	88,120	121,060	151,640	205,210	211,360	209,190	216,430	220,230
Percent of Total Generation								
Materials	**1960**	**1970**	**1980**	**1990**	**1995**	**1996**	**1997**	**1998**
Paper and Paperboard	34.00%	36.60%	36.40%	35.40%	38.60%	38.10%	38.50%	38.20%
Glass	7.60%	10.50%	10.00%	6.40%	6.10%	5.90%	5.50%	5.70%
Metals								
Ferrous	11.70%	10.20%	8.30%	6.20%	5.50%	5.70%	5.70%	5.60%
Aluminum	0.40%	0.70%	1.10%	1.40%	1.40%	1.40%	1.40%	1.40%
Other Nonferrous	0.20%	0.60%	0.80%	0.50%	0.60%	0.60%	0.60%	0.60%
Total Metals	12.30%	11.40%	10.20%	8.10%	7.50%	7.70%	7.70%	7.60%
Plastics	0.40%	2.40%	4.50%	8.30%	8.90%	9.40%	9.90%	10.20%
Rubber and Leather	2.10%	2.50%	2.80%	2.80%	2.90%	3.00%	3.00%	3.10%
Textiles	2.00%	1.70%	1.70%	2.80%	3.50%	3.70%	3.80%	3.90%
Wood	3.40%	3.10%	4.60%	6.00%	4.90%	5.20%	5.30%	5.40%
Other **	0.10%	0.60%	1.70%	1.60%	1.70%	1.80%	1.70%	1.80%
Total Materials in Products	**62.00%**	**68.80%**	**71.80%**	**71.40%**	**74.20%**	**74.70%**	**75.60%**	**75.90%**
Other Wastes								
Food Wastes	13.80%	10.60%	8.60%	10.10%	10.30%	10.40%	10.10%	10.00%
Yard Trimmings	22.70%	19.20%	18.10%	17.10%	14.00%	13.30%	12.80%	12.60%
Miscellaneous Inorganic Wastes	1.50%	1.50%	1.50%	1.40%	1.50%	1.50%	1.50%	1.50%
Total Other Wastes	38.00%	31.20%	28.20%	28.60%	25.80%	25.30%	24.40%	24.10%
Total MSW Generated - Weight %	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

* Generation before recovery or combustion. Does not include constuction and demolition debris, industrial process wastes, or cer

**Includes electrolytes in batteries and fluff pulp, feces, and urine in diposbale diapers.

Details may not add to totals dir to rounding.

Data Table #1	HOW MUCH DO YOU WASTE?	NAME ___________________

Name	Mass Collected lbs.	# in House	House Mass (1 day)	One Week		One Month		One Year	
1				You	Household	You	Household	You	Household
2									
3									
4									
Mean									

Data Table #2	WHAT IS THAT GARBAGE?	NAME ___________________

Item Name	Group	Composition	Natural Resource	Origin	Organic or Inorganic	Toxic?	Decomposition Time
1							
2							
3							
4							